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<b>UTILITY PATENT APPLICATION TRANSMITTAL</b> (Only for new nonprovisional applications under 37 C.F.R. § 1.53(b))	Attorney Docket No.	06052 USA
	First Inventor or Application Identifier	Hoanh Nang Pham
	Title	Apparatus and Method For Hydrocarbon Reforming ...
	Express Mail Label No.	EL685717705US

<b>APPLICATION ELEMENTS</b> See MPEP chapter 600 concerning utility patent application contents.	<b>ADDRESS TO:</b> Assistant Commissioner for Patents Box Patent Application Washington, DC 20231
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<p>1. <input checked="" type="checkbox"/> * Fee Transmittal Form (e.g., PTO/SB/17) (Submit an original and a duplicate for fee processing)</p> <p>2. <input checked="" type="checkbox"/> Specification [Total Pages <b>26</b>] (preferred arrangement set forth below)</p> <ul style="list-style-type: none"><li>- Descriptive title of the invention</li><li>- Cross References to Related Applications</li><li>- Statement Regarding Fed sponsored R &amp; D</li><li>- Reference to Microfiche Appendix</li><li>- Background of the invention</li><li>- Brief Summary of the invention</li><li>- Brief Description of the Drawings (if filed)</li><li>- Detailed Description</li><li>- Claim(s)</li><li>- Abstract of the Disclosure</li></ul> <p>3. <input checked="" type="checkbox"/> Drawing(s) (35 U.S.C. 113) [Total Sheets <b>14</b>]</p> <p>4. Oath or Declaration [Total Pages <b>4</b>]</p> <p>a. <input checked="" type="checkbox"/> Newly executed (original or copy)</p> <p>b. <input type="checkbox"/> Copy from a prior application (37 C.F.R. § 1.63(d)) (for continuation/divisional with Box 16 completed)</p> <p>i. <input type="checkbox"/> <b>DELETION OF INVENTOR(S)</b> Signed statement attached deleting inventor(s) named in the prior application, see 37 C.F.R. §§ 1.63(d)(2) and 1.33(b).</p> <p><b>* NOTE FOR ITEMS 1 &amp; 13: IN ORDER TO BE ENTITLED TO PAY SMALL ENTITY FEES, A SMALL ENTITY STATEMENT IS REQUIRED (37 C.F.R. § 1.27), EXCEPT IF ONE FILED IN A PRIOR APPLICATION IS RELIED UPON (37 C.F.R. § 1.28).</b></p>	<p>5. <input type="checkbox"/> Microfiche Computer Program (Appendix)</p> <p>6. Nucleotide and/or Amino Acid Sequence Submission (if applicable, all necessary)</p> <p>a. <input type="checkbox"/> Computer Readable Copy</p> <p>b. <input type="checkbox"/> Paper Copy (identical to computer copy)</p> <p>c. <input type="checkbox"/> Statement verifying identity of above copies</p>
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☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No: \_\_\_\_\_

Prior application information: Examiner \_\_\_\_\_ Group / Art Unit: \_\_\_\_\_

**For CONTINUATION or DIVISIONAL APPS only:** The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 4b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

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Name (Print/Type)	Geoffrey L. Chase	Registration No. (Attorney/Agent)	28,059
Signature		Date	Sept. 20, 2000

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Small Entity payments must be supported by a small entity statement,  
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See 37 C.F.R. §§ 1.27 and 1.28.

TOTAL AMOUNT OF PAYMENT (\$) 984.00

### Complete if Known

Application Number	
Filing Date	September 20, 2000
First Named Inventor	Hoanh Nang Pham
Examiner Name	
Group / Art Unit	
Attorney Docket No.	06052 USA

### METHOD OF PAYMENT (check one)

1. ☒ The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

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### FEE CALCULATION

#### 1. BASIC FILING FEE

Large Entity Fee Code (\$)	Small Entity Fee Code (\$)	Fee Description	Fee Paid
101 690	201 345	Utility filing fee	690.0
106 310	206 155	Design filing fee	
107 480	207 240	Plant filing fee	
108 690	208 345	Reissue filing fee	
114 150	214 75	Provisional filing fee	

SUBTOTAL (1) (\$) 690.00

#### 2. EXTRA CLAIM FEES

Total Claims	Extra Claims	Fee from below	Fee Paid
32	-20** = 12	x 18	= 216.00
Independent Claims 4	-3** = 1	x 78	= 78.00
Multiple Dependent			

\*\*or number previously paid, if greater; For Reissues, see below

Large Entity Fee Code (\$)	Small Entity Fee Code (\$)	Fee Description
103 18	203 9	Claims in excess of 20
102 78	202 39	Independent claims in excess of 3
104 260	204 130	Multiple dependent claim, if not paid
109 78	209 39	** Reissue independent claims over original patent
110 18	210 9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) (\$) 294.00

### FEE CALCULATION (continued)

#### 3. ADDITIONAL FEES

Large Entity Fee Code (\$)	Small Entity Fee Code (\$)	Fee Description	Fee Paid
105 130	205 65	Surcharge - late filing fee or oath	
127 50	227 25	Surcharge - late provisional filing fee or cover sheet	
139 130	139 130	Non-English specification	
147 2,520	147 2,520	For filing a request for reexamination	
112 920*	112 920*	Requesting publication of SIR prior to Examiner action	
113 1,840*	113 1,840*	Requesting publication of SIR after Examiner action	
115 110	215 55	Extension for reply within first month	
116 380	216 190	Extension for reply within second month	
117 870	217 435	Extension for reply within third month	
118 1,360	218 680	Extension for reply within fourth month	
128 1,850	228 925	Extension for reply within fifth month	
119 300	219 150	Notice of Appeal	
120 300	220 150	Filing a brief in support of an appeal	
121 260	221 130	Request for oral hearing	
138 1,510	138 1,510	Petition to institute a public use proceeding	
140 110	240 55	Petition to revive - unavoidable	
141 1,210	241 605	Petition to revive - unintentional	
142 1,210	242 605	Utility issue fee (or reissue)	
143 430	243 215	Design issue fee	
144 580	244 290	Plant issue fee	
122 130	122 130	Petitions to the Commissioner	
123 50	123 50	Petitions related to provisional applications	
126 240	126 240	Submission of Information Disclosure Stmt	
581 40	581 40	Recording each patent assignment per property (times number of properties)	
146 690	246 345	Filing a submission after final rejection (37 CFR § 1.129(a))	
149 690	249 345	For each additional invention to be examined (37 CFR § 1.129(b))	

Other fee (specify) \_\_\_\_\_

Other fee (specify) \_\_\_\_\_

\* Reduced by Basic Filing Fee Paid

SUBTOTAL (3) (\$)

### SUBMITTED BY

Name (Print/Type)	Geoffrey L. Chase	Registration No. (Attorney/Agent)	28,059	Complete (if applicable)	
Signature	<i>Geoffrey L. Chase</i>	Telephone	610-481-7265	Date	September 20, 2000

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TITLE OF THE INVENTION:

APPARATUS AND METHOD FOR  
HYDROCARBON REFORMING PROCESS

CROSS-REFERENCE TO RELATED APPLICATIONS

5 Not applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR  
DEVELOPMENT

Not applicable.

10 BACKGROUND OF THE INVENTION

This invention relates to processes for the production of a gas containing hydrogen and carbon oxides (such as methanol synthesis gas) by steam reforming a hydrocarbon feedstock, and in particular to an apparatus and method for hydrocarbon reforming processes which utilize high grade sensible heat of flue gas and product synthesis gas to generate additional product gas and minimize steam export.

15 The steam reforming process is a well known chemical process for hydrocarbon reforming. A hydrocarbon and steam mixture (a "mixed-feed") reacts in the presence of a catalyst to form hydrogen, carbon monoxide and carbon dioxide. Since the reforming reaction is strongly endothermic, heat must be supplied to the reactant mixture, such as by heating the tubes in a furnace or reformer. The amount of reforming achieved depends on the temperature of the gas leaving the catalyst; exit temperatures in the range 700° - 900° C are typical for conventional hydrocarbon reforming.

20 Conventional catalyst steam reformer processes combust fuel to provide the energy required for the reforming reaction. In a reformer of such a conventional process, fuel typically is fired co-current to incoming cold feed gas to maximize heat flux through

the tube wall(s) by radiant heat transfer directly from the flame. Downstream from the burner end, both the product gas and the flue gas exit at relatively high temperatures. The energy content of these gases usually is recovered by preheating reformer feed gas or by generating steam. As a result, the process generates excess steam that must be  
5 exported to improve the overall efficiency of the steam reforming process and to make the process economically feasible in view of the fact that significant equipment has been added to generate that excess steam.

Each of the processes disclosed in U.S. Pat. Nos. 5,199,961 (Ohsaki, *et al.*) and 4,830,834 (Stahl, *et al.*) and in European Pat. No. EP 0 911 076 A1 (Stahl) utilize a  
10 portion of the available sensible energy within the reformer vessel, thereby allowing the product gas and the flue gas to exit at lower temperatures than the corresponding exit temperatures for conventional steam reforming. These reforming processes receive heat from the combustible fuel by using a combination of: (1) an equalizing wall (made of tiles, refractory, or metals) to receive radiant heat directly from the flame from which heat  
15 is transferred to the reformer tube(s) by radiant heat; and (2) an arrangement of a counter-current flow of the hot flue gas with the incoming feed which transfers sensible energy to the incoming feed by convection through the tube wall. These techniques allow the temperature of the reformer tube skin to be controlled within the design limit; otherwise, the temperature will be excessive due to the high intensive radiant heat of the  
20 flame. However, these processes suffer a heat flux limitation by avoiding the direct radiant heat from the flame to the tube as commonly used in conventional reformers.

U.S. Pat. No. 5,945,074 (Waterreus, *et al.*) discloses tunnels to remove combustion product gases from a combustion chamber. The tunnels serve to balance or maintain uniform flow of the combustion gases through a furnace but do not utilize the  
25 high temperature sensible heat of the combustion gas.

To recover the sensible heat of product gas, prior art hydrocarbon reforming processes use a tube within a tube (tube-in-tube) arrangement with catalyst in the annuli. The cold feed in the annuli flows counter-current with the combustion or the flue gas from the outside and absorbs the combustion heat of both the radiant and convection heat transfers through the outside tube wall. The reformed gas flow is reversed at the end of the catalyst bed and enters the inner-most passage of the tube. The reformed gas then gives up heat to the counter-current flow of the incoming cold feed. The convection heat transfer process from the hot product gas to the reforming reactions is not effective however, because there is no temperature driving force at the inversion point. As a result, more heat transfer surface area is required to utilize the product gas sensible heat. Consequently, the lack of intensive radiant heat transfer from the outside and the ineffective convection heat transfer in the inside result in a large tube-in-tube requirement.

It is desired to have an apparatus and a method for hydrocarbon reforming processes which overcome the difficulties, problems, limitations, disadvantages and deficiencies of the prior art to provide better and more advantageous results.

It is further desired to have an apparatus and a method for a hydrocarbon reforming process which utilize high grade sensible heat of flue gas and product synthesis gas to generate additional product gas and minimize steam export.

It is still further desired to have a more efficient and economic process and apparatus for hydrocarbon reforming.

#### BRIEF SUMMARY OF THE INVENTION

The invention is an apparatus and method for a hydrocarbon reforming process. A first embodiment of the apparatus includes a vessel having at least one partition wall disposed in the vessel. The at least one partition wall divides the vessel into a plurality

of chambers, including at least one combustion chamber and at least one convection chamber. Each of the chambers has a first end and a second end opposite the first end. At least one burner is disposed in the combustion chamber. The burner is adapted to combust a fuel, thereby generating a flue gas having sensible heat. The apparatus also includes communication means between the combustion chamber and the convection chamber whereby at least a portion of the flue gas flows from the combustion chamber to the convection chamber at a first location adjacent the first end of the convection chamber. The apparatus also includes transfer means whereby at least a portion of the flue gas flows to a second location in the convection chamber adjacent the second end of the convection chamber. The apparatus also includes multiple reaction chambers, including a first reaction chamber and a second reaction chamber. A substantial portion of the first reaction chamber is disposed in the combustion chamber, and a substantial portion of the second reaction chamber is disposed in the convection chamber.

In a preferred embodiment, the reaction chambers, which preferably are tubular devices, are reformer tubes. The tubular devices may be reformer radiant tubes or tube-in-tube devices.

There are many variations of the first embodiment. In one variation, a first portion of a mixed-feed flows through the first reaction chamber co-currently with a flow of the flue gas in the combustion chamber, and a second portion of the mixed-feed flows through the second reaction chamber counter-currently with the flow of the flue gas in the convection chamber.

In another variation, a substantial portion of the first reaction chamber is substantially vertical within the combustion chamber. In yet another variation, a substantial portion of a second reaction chamber is substantially vertical within the convection chamber.

In another variation of the first embodiment, the second reaction chamber is a tube-in-tube. In a variation of that variation, a first portion of a mixed-feed flows through the first reaction chamber co-currently with a flow of the flue gas in the combustion chamber, and a second portion of the mixed-feed flows through the second reaction chamber counter-currently with the flow of the flue gas in the convection chamber. In a variation of that variation, the first portion of the mixed-feed flows in an annular portion of the tube-in-tube, and a product synthesis gas flows in an inner tubular portion of the tube-in-tube counter-currently with the first portion of the mixed-feed.

In another variation of the first embodiment, the first reaction chamber is a tube-in-tube. In a variation of that variation, a first portion of a mixed-feed flows through the first reaction chamber co-currently with a flow of the flue gas in the combustion chamber, and a second portion of the mixed-feed flows through the second reaction chamber counter-currently with the flow of the flue gas in the convection chamber. In a variation of that variation, the first portion of the mixed-feed flows in an annular portion of the tube-in-tube, and a product synthesis gas flows in an inner tubular portion of the tube-in-tube counter-currently with the first portion of the mixed-feed.

Another embodiment of the invention is similar to the first embodiment but includes communication means between the first reaction chamber and the second reaction chamber, whereby a fluid flows from or to said first reaction chamber to or from said second reaction chamber.

In yet another embodiment of the invention, the apparatus includes at least one combustion chamber and at least one convection chamber, each of the chambers having a first end and a second end opposite the first end. At least one burner is disposed in the combustion chamber. The burner is adapted to combust a fuel, thereby generating a flue gas having sensible heat. The apparatus also includes communication means between the combustion chamber and the convection chamber whereby at least a

portion of the flue gas flows from the combustion chamber to the convection chamber at a first location adjacent the first end of the convection chamber. The apparatus also includes transfer means whereby at least a portion of the flue gas flows to a second location in the convection chamber adjacent the second end of the convection chamber.

- 5 The apparatus also includes multiple reaction chambers, including a first reaction chamber and a second reaction chamber. A substantial portion of the first reaction chamber is disposed in the combustion chamber, and a substantial portion of the second reaction chamber is disposed in the convection chamber.

10 In a preferred embodiment of this embodiment, the reaction chambers, which preferably are tubular devices, are reformer tubes. The tubular devices may be reformer radiant tubes or tube-in-tube devices.

15 Another aspect of the invention is an assembly of multiple units for a hydrocarbon reforming process, each unit comprising an apparatus as in the first embodiment (or another of the embodiments). Many embodiments of this aspect are discussed below and illustrated in the drawings. For example, in one embodiment, the assembly also includes at least one duct connecting a first convection chamber and a second convection chamber of the at least one convection chamber in at least one unit. Another embodiment includes those same features but also includes at least one convection pass in communication with the at least one duct.

- 20 Yet another aspect of the invention is a method for producing a product from a steam reforming process. A first embodiment of the method includes multiple steps. The first step is to provide at least one combustion chamber, at least one convection chamber, and a communication means between the combustion chamber and the convection chamber, each of the chambers having a first end and a second end opposite  
25 the first end, the communication means being adapted to transmit a flow of flue gas from the combustion chamber to the convection chamber. The second step is to combust a



fuel in the combustion chamber, thereby generating a combustion heat and a flue gas having a sensible heat. The third step is to transfer at least a portion of the flue gas from the combustion chamber to the convection chamber, wherein at least a portion of the transferred flue gas flows from a first location adjacent the first end of the convection chamber to a second location adjacent the second end of the convection chamber. The fourth step is to feed a first portion of a mixed-feed to a first reaction chamber, a substantial portion of the first reaction chamber being disposed in the combustion chamber, wherein the first portion of the mixed-feed absorbs at least a portion of the combustion heat. The fifth step is to feed a second portion of the mixed-feed to a second reaction chamber, a substantial portion of the second reaction chamber being disposed in the convection chamber, wherein the second portion of the mixed-feed absorbs at least a portion of the sensible heat of the flue gas flowing from the first location to the second location in the convection chamber.

There are many variations of the first embodiment of the method. In one variation, the first portion of the mixed-feed flows co-currently with a flow of flue gas in the combustion chamber. In another variation, the mixed-feed flows counter-currently with the flue gas flowing from the first location to the second location in the convection chamber.

Another embodiment of the method is similar to the first embodiment of the method but includes an additional step. The additional step is to withdraw a stream of the product from the first reaction chamber. In a variation of this embodiment, the stream of the product flows counter-currently with the first portion of the mixed-feed.

Yet another embodiment of the method is similar to the first embodiment of the method but includes an additional step. The additional step is to withdraw a stream of the product from the second reaction chamber. In a variation of this embodiment, the stream of the product flows counter-currently with the second portion of the mixed-feed.

Still yet another embodiment of the method is similar to the first embodiment of the method, but includes an additional step. The additional step is to provide communication means between the first reaction chamber and the second reaction chamber whereby a stream of the product flows from or to the first reaction chamber to  
5 or from the second reaction chamber.

In all of the embodiments of the method, the reaction chambers preferably are tubular devices, such as reformer tubes. The tubular devices may be reformer radiant tubes or tube-in-tube devices.

#### 10 BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

Embodiments of the invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a schematic cross-sectional plan view of the apparatus for one embodiment of the invention;

15 Figure 2 is a schematic partial cross-sectional elevation of the embodiment of the invention shown in Figure1;

Figures 3, 4 and 5 are schematic cross-sectional plan views of the vessel of the present invention having different shapes - - square, circular and hexagonal;

20 Figure 6 is a schematic partial cross-sectional elevation of another embodiment of the invention;

Figure 7 is a schematic partial cross-sectional elevation of another embodiment of the invention;

Figure 8 is a schematic partial cross-sectional elevation of another embodiment of the invention;

25 Figure 9 is a schematic cross-sectional plan view of a modular arrangement of multiple square units of the apparatus of the present invention;

Figure 10 is a schematic partial cross-sectional plan view of two modular units of the apparatus side-by-side with ducts connecting the convection chambers of both units to a common convection pass located between the units;

Figure 11 is a partial cross-sectional plan view of two modular units of the apparatus side-by-side with ducts connecting the convection chambers of both units to a common convection pass located on one side of one of the units;

Figure 12 is a partial cross-sectional plan view of two modular units of the apparatus side-by-side with ducts on the outside connecting the convection chambers of the units to a common convection pass located between the units;

Figure 13 is a partial cross-sectional plan view of two modular units of the apparatus side-by-side with ducts on the outside connecting the convection chambers of the units to a common convection pass located on one side of one of the units;

Figure 14 is a schematic diagram of an arrangement of four modular units of the apparatus side-by-side with ducts on the inside connecting the convection chambers of the units to a common convection pass;

Figure 15 is a schematic diagram of an arrangement of four modular units of the apparatus side-by-side with ducts on the outside connecting the convection chambers of the units to a common convection pass;

Figure 16 is a schematic diagram of an arrangement of eight modular units of the apparatus side-by-side with ducts on the inside connecting the convection chambers of the units to a common convection pass;

Figure 17 is a schematic diagram of an arrangement of eight modular units of the apparatus side-by-side with ducts on the outside connecting the convection chambers of the units to a common convection pass;

Figure 18 is a schematic cross-sectional plan view of the apparatus for another embodiment of the invention; and

Figure 19 is a schematic partial cross-sectional elevation of the embodiment of the invention shown in Figure 18.

#### DETAILED DESCRIPTION OF THE INVENTION

5           The present invention uses partition walls 14 to separate the furnace or reformer into two different types of chambers: (1) a combustion chamber 16, and (2) convection chambers 18, as shown in Figures 1 and 2.

10           The combustion chamber 16 contains one or more burners 24 and conventional radiant tubes and/or a conventional tube-in-tube arrangement exposed directly to the burner flame, similar to that in conventional reformers. However, the co-current flow of the process and combustion product gases of the present invention provides maximum heat flux to the reformer tubes without the limitations observed in the prior art.

15           The convection chambers 18 do not contain a burner but receive the hot combustion products from the combustion chamber 16. The convection chambers also contain conventional reformer tubes and/or a tube-in-tube arrangement to recover the sensible heat from both the flue gas from the outside and the hot product gas from the inside. The counter-current flow of the mixed-feed (steam plus hydrocarbon feed) and the hot combustion gas in the convection chambers allows the combustion gas to leave the reformer at a substantially lower temperature as compared to a conventional  
20 reformer. Hence, no shock coil is required and a much smaller convective pass is needed to recover the remaining flue gas sensible heat. In addition, the convection chambers serve as a means to provide uniform flow of combustion gas in the combustion chamber. Also, the counter-current flow of the mixed-feed and the synthesis product gas allows the synthesis gas to leave the reformer at a relatively low  
25 temperature that permits use of a simple kettle boiler rather than a complex process gas waste heat boiler as in conventional steam reforming processes.

Referring to Figures 1 and 2, the apparatus 10 of the present invention includes a refractory lined vessel 12. The vessel contains partition walls 14 that divide the inside of the vessel into a combustion chamber 16 (or radiant section) containing burner(s) 24 and one or more smaller convection chambers 18 (or convection sections) used as a means to remove combustion products from the combustion chamber. At the far end opposite the burner end of the vessel, the partition walls have one or more openings 20 that allow the combustion products from the combustion chamber to enter the smaller convection chambers and return to the burner end before exiting the vessel. In the convection chambers, baffles (not shown) can be used to enhance convective heat transfer. The convection chambers are designed to maintain high flue gas velocity and to thereby maintain high convection heat transfer before the flue gas exits the vessel. Each partition wall can be made from a sheet of high emissivity metal insulated on the combustion side, or can be a refractory wall made of a composite of conventional refractory materials, such as high temperature fired bricks. In the latter case, the convection side of the refractory wall is coated with a high emissivity material.

Conventional reformer radiant tubes 22 or conventional tube-in-tube devices with catalyst in their annuli are used in the combustion chamber 16 to utilize high intensive radiant heat directly from the flame of the burner(s) 24. Conventional reformer catalyst tubes 26 - - tube-in-tube devices with catalyst in their annuli, or tube-in-tube devices that connect with the radiant tubes from the combustion chamber to receive the hot product gas from the radiant tubes - - are placed in the convection chambers 18 to recover the sensible heat from the flue gas and the product gas from the reforming reaction.

Figures 3, 4 and 5 show several different shapes of the vessel 12 that may be used for the present invention. Feasible shapes include but are not limited to cylindrical, triangular, square, rectangular, and hexagonal. Any shape may be used that allows for

partition walls 14 between at least one combustion chamber 16 (having at least one burner 24) and at least one convection chamber 18 (having means 32 for a flue gas exit).

Figure 2 shows one configuration having a conventional radiant tube 22 in the combustion chamber 16 and tube-in-tube devices 26 in the convection chambers 18. At the end opposite the burner end, the radiant tube and the tube-in-tube devices are connected to a common manifold (not shown) by pigtails 28 or by individual pigtails 30 that directly transfer the hot synthesis gas from the radiant tube to the tube-in-tube devices. In this arrangement, mixed-feed enters the radiant tube at the inlet 38 and the tube-in-tube devices at inlets 34. Flue gas exits the convection chambers at flue gas exits 32, and product synthesis gas exits the tube-in-tube devices at syngas outlets 36. The mixed-feed in the radiant tube flows co-current with the combustion products in the combustion chamber. The mixed-feed in the annuli of the tube-in-tube devices flows counter-current to the hot flue gas in the convection chambers. The sensible heat of the flue gas and the sensible heat of the product gas are utilized to generate more product synthesis gas. The temperatures of the exit flue gas and the product gas can be varied to generate additional steam if needed.

Figure 6 shows another configuration of the apparatus 10 of the present invention arranged differently than the configuration in Figure 2. In Figure 6, conventional radiant tubes 122 are placed in the convection chambers 18 and a tube-in-tube device 126 with catalyst in the annuli is located in the combustion chamber 16. Mixed-feed enters the radiant tubes at inlets 138 and the tube-in-tube device at inlet 134. The hot synthesis gas is flowed from the radiant tubes in the convection chambers to the tube-in-tube device in the combustion chamber. Product synthesis gas exits the tube-in-tube device at syngas outlet 136.

Figure 8 shows another configuration of the apparatus 10 in which tube-in-tube devices 226 with catalyst in the annuli are used in both the combustion chamber 16 and

the convection chambers 18. Mixed-feed enters the tube-in-tube devices at inlets 234, and product synthesis gas exits at syngas outlets 236. This configuration utilizes high grade heat of the product gas in its own tube, minimizes hot gas transfer lines, makes it easy to add additional capacity, and makes it easy to vary steam export if necessary.

5           Figure 7 shows another configuration of the apparatus 10 in which conventional radiant tubes 322 are used in both the combustion chamber 16 and the convection chambers 18. In this arrangement, only the high grade sensible heat of the flue gas is utilized to generate more products. Mixed-feed enters the radiant tubes at inlets 338, and product synthesis gas exits via pigtails 28. The sensible heat of the product gas can  
10           be used to generate extra steam if needed or additional product externally in a separate conventional device such as shown in U.S. Pat. Nos. 5,122,299 (Le Blanc) and 5,006,131 (Karafian, *et al.*).

          All burner arrangements in the combustion chambers shown in Figures 2, 6 and 8  
15           can be repositioned to achieve down-firing. The process gas (or mixed-feed) flow can be arranged appropriately to maximize heat absorbed from the combustion of fuel. Persons skilled in the art will recognize that the burners also may be located other than shown in the drawings, such as at any point on the side walls of the combustion chamber.

          Figure 9 shows an arrangement of a reformer that combines several square modular units of the apparatus 10 to increase syngas production capacity.

20           Figure 10 shows a configuration having two modular units of the apparatus 10 side-by-side with flue gas ducts 40 connecting the convection chambers 18 of both the units to a common convection pass 42 located between the units. Additional units can be added above or below the units shown and/or laterally (*e.g.*, to the right or to the left of the units shown).

25           Figure 11 shows another configuration having two modular units of the apparatus 10 side-by-side with flue gas ducts 40 connecting the convection chambers 18 of both

units to a common convection pass 42 located on one side of one of the units. Additional units can be added above or below the units shown and/or laterally (e.g., to the right or to the left of the units shown).

Figure 12 shows another configuration having two modular units of the apparatus 10 side-by-side with flue gas ducts 40 on the outside connecting all convection chambers 18 to a common convection pass 42 located between the units. Additional units can be added above or below the units shown and/or laterally (e.g., to the right or to the left of the units shown).

Figure 13 shows another configuration having two modular units of the apparatus 10 side-by-side with flue gas ducts 40 on the outside connecting all convection chambers 18 to a common convection pass 42 located on one side of one of the units. Additional units can be added above or below the units shown and/or laterally (e.g., to the right or to the left of the units shown).

Figure 14 shows a configuration having four modular units of the apparatus 10 side-by-side with flue gas ducts 40 on the inside connecting all convection chambers 18 to a common convection pass 42.

Figure 15 shows another configuration having four modular units of the apparatus 10 side-by-side with flue gas ducts 40 on the outside connecting all convection chambers 18 to a common convection pass 42.

Figure 16 shows a configuration having eight modular units of the apparatus 10 side-by-side with flue gas ducts 40 on the inside connecting all convection chambers 18 to a common convection pass 42.

Figure 17 shows another configuration having eight modular units of the apparatus 10 side-by-side with flue gas ducts 40 on the outside connecting all convection chambers 18 to a common convection pass 42.



Persons skilled in the art will recognize that it is possible to have other configurations of modular units and various other arrangements of the combustion and convection chambers of the present invention. For example, Figures 18 and 19 show an arrangement where there is not a partition wall between the combustion chamber 16 and the convection chamber 18, the two chambers being connected by a duct 45. More than one convection chamber may be connected to the duct 45 to receive flue gas from the combustion chamber 16. Alternatively, another convection chamber(s) may be connected to the combustion chamber 16 via another duct(s) to receive flue gas from the combustion chamber. For example, referring to Figures 18 and 19, a second convection chamber could be connected via a second duct to the combustion chamber on the left side of the combustion chamber (*i.e.*, directly opposite the convection chamber and duct shown), thereby "balancing" the apparatus.

The sensible heat recovery technique of the present invention allows to (1) significantly reduce the heat exchanger equipment to recover the sensible heat of both the synthesis gas and the combustion products, (2) utilize high grade waste heat from flue gas for reforming instead of generating excess steam as in conventional steam reforming processes, (3) more effectively use expensive reformer tubes to recover sensible heat for reforming reactions, (4) effectively integrate the hot product gas from the reformer tube in the combustion chamber and the tube-in-tube in the convection chambers to utilize high grade sensible heat for reforming reactions, (5) enhance convective heat transfer from the product gas by increasing temperature driving force, (6) minimize equipment and heat loss due to transfer lines compared to conventional techniques, (7) vary steam export as demanded by controlling the combustion or product gas exit temperatures, (8) combine the radiant and convection sections in one compact unit that may be built in the shop and may be used as a modular unit in a configuration where several units set side-by-side are connected with simple connections at a field site

to achieve or to expand the synthesis gas production capacity, and (9) use a small convection chamber that can be designed to maximize convective heat transfer by maintaining high flue gas velocity.

Although illustrated and described herein with reference to certain specific  
5 embodiments, the present invention is nevertheless not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the spirit of the invention.

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## CLAIMS

1. An apparatus for a hydrocarbon reforming process, comprising:
  - at least one combustion chamber having a first end and a second end opposite said first end;
  - 5 at least one convection chamber having a first and a second end opposite said first end;
  - at least one burner disposed in said combustion chamber, said burner adapted to combust a fuel, thereby generating a flue gas having sensible heat;
  - 10 communication means between said combustion chamber and said convection chamber whereby at least a portion of said flue gas flows from said combustion chamber to said convection chamber at a first location adjacent said first end of said convection chamber;
  - 15 transfer means whereby at least a portion of said flue gas flows to a second location in said convection chamber adjacent said second end of said convection chamber;
  - a first reaction chamber, a substantial portion of said first reaction chamber disposed in said combustion chamber; and
  - 20 a second reaction chamber, a substantial portion of said second reaction chamber disposed in said convection chamber.
2. An apparatus for a hydrocarbon reforming process, comprising:
  - 25 a vessel having at least one partition wall disposed in said vessel, said at least one partition wall dividing said vessel into a plurality of chambers, including at least one combustion chamber

and at least one convection chamber, each of said chambers having a first end and a second end opposite said first end;

at least one burner disposed in said combustion chamber, said burner adapted to combust a fuel, thereby generating a flue gas having sensible heat;

communication means between said combustion chamber and said convection chamber whereby at least a portion of said flue gas flows from said combustion chamber to said convection chamber at a first location adjacent said first end of said convection chamber;

transfer means whereby at least a portion of said flue gas flows to a second location in said convection chamber adjacent said second end of said convection chamber;

a first reaction chamber, a substantial portion of said first reaction chamber disposed in said combustion chamber; and

a second reaction chamber, a substantial portion of said second reaction chamber disposed in said convection chamber.

3. An apparatus as in claim 2, further comprising:

communication means between said first reaction chamber and said second reaction chamber, whereby a fluid flows from or to said first reaction chamber to or from said second reaction chamber.

4. An apparatus as in claim 2, wherein the substantial portion of said first reaction chamber is substantially vertical within said combustion chamber.

5. An apparatus as in claim 2, wherein the substantial portion of said second reaction chamber is substantially vertical within said convection chamber.

5 6. An apparatus as in claim 2, wherein said second reaction chamber is a tube-in-tube.

7. An apparatus as in claim 2, wherein said first reaction chamber is a tube-in-tube.

10 8. An assembly of multiple units for a hydrocarbon reforming process, each unit comprising an apparatus as in claim 2.

15 9. An assembly as in claim 8 further comprising at least one duct connecting a first convection chamber and a second convection chamber of said at least one convection chamber in at least one unit.

20 10. An assembly as in claim 9 further comprising at least one convection pass in communication with said at least one duct.

25 11. An apparatus as in claim 2, wherein a first portion of a mixed-feed flows through said first reaction chamber co-currently with a flow of said flue gas in said combustion chamber, and a second portion of said mixed-feed flows through said second reaction chamber counter-currently with said flow of said flue gas in said convection chamber.

12. An apparatus as in claim 6, wherein a first portion of a mixed-feed flows through said first reaction chamber co-currently with a flow of said flue gas in said combustion chamber, and a second portion of said mixed-feed flows through said second reaction chamber counter-currently with said flow of said flue gas in said convection chamber.

13. An apparatus as in claim 7, wherein a first portion of a mixed-feed flows through said first reaction chamber co-currently with a flow of said flue gas in said combustion chamber, and a second portion of said mixed-feed flows through said second reaction chamber counter-currently with said flow of said flue gas in said convection chamber.

14. An apparatus as in claim 12, wherein said first portion of said mixed-feed flows in an annular portion of said tube-in-tube, and a product synthesis gas flows in an inner tubular portion of said tube-in-tube counter-currently with said first portion of said mixed-feed.

15. An apparatus as in claim 13, wherein said first portion of said mixed-feed flows in an annular portion of said tube-in-tube, and a product synthesis gas flows in an inner tubular portion of said tube-in-tube counter-currently with said first portion of said mixed-feed.

16. An apparatus for a hydrocarbon reforming process, comprising:  
a vessel having at least one partition wall disposed in said vessel, said at least one partition wall dividing said vessel into a plurality of chambers, including at least one combustion chamber

and at least one convection chamber, each of said chambers having a first end and a second end opposite said first end;

at least one burner disposed in said combustion chamber, said burner adapted to combust a fuel, thereby generating a flue gas having sensible heat;

communication means between said combustion chamber and said convection chamber whereby at least a portion of said flue gas flows from said combustion chamber to said convection chamber at a first location adjacent said first end of said convection chamber;

transfer means whereby at least a portion of said flue gas flows to a second location in said convection chamber adjacent said second end of said convection chamber;

a first reformer tube, a substantial portion of said first reformer tube disposed in said combustion chamber; and

a second reformer tube, a substantial portion of said second reformer tube disposed in said convection chamber.

17. An apparatus as in claim 16, further comprising:

communication means between said first reformer tube and said second reformer tube, whereby a fluid flows from or to said first reformer tube to or from said second reformer tube.

18. An assembly of multiple units for a hydrocarbon reforming

process, each unit comprising an apparatus as in claim 16.

19. An assembly as in claim 18 further comprising at least one duct connecting a first convection chamber and a second convection chamber of said at least one convection chamber in at least one unit.

5 20. An assembly as in claim 19 further comprising at least one convection pass in communication with said at least one duct.

21. An apparatus as in claim 1, further comprising:

10 communication means between said first reaction chamber and said second reaction chamber, whereby a fluid flows from or to said first reaction chamber to or from said second reaction chamber.

15 22. An assembly of multiple units for a hydrocarbon reforming process, each unit comprising an apparatus as in claim 1.

23. An assembly as in claim 22 further comprising at least one duct connecting a first convection chamber and a second convection chamber of said at least one convection chamber in at least one unit.

20 24. An assembly as in claim 23 further comprising at least one convection pass in communication with said at least one duct.

25 25. A method for producing a product from a steam reforming process, comprising the steps of:



providing at least one combustion chamber, at least one convection chamber, and a communication means between said combustion chamber and said convection chamber, each of said chambers having a first end and a second end opposite said first end, and said communication means being adapted to transmit a flow of flue gas from said combustion chamber to said convection chamber;

combusting a fuel in said combustion chamber, thereby generating a combustion heat and a flue gas having a sensible heat;

transferring at least a portion of said flue gas from said combustion chamber to said convection chamber, wherein at least a portion of said transferred flue gas flows from a first location adjacent said first end of said convection chamber to a second location adjacent said second end of said convection chamber;

feeding a first portion of a mixed-feed to a first reaction chamber, a substantial portion of said first reaction chamber being disposed in said combustion chamber, wherein said first portion of said mixed-feed absorbs at least a portion of said combustion heat; and

feeding a second portion of said mixed-feed to a second reaction chamber, a substantial portion of said second reaction chamber being disposed in said convection chamber, wherein said second portion of said mixed-feed absorbs at least a portion of said sensible heat of said flue gas flowing from said first location to said second location in said convection chamber.

26. A method as in claim 25, comprising the further step of withdrawing a stream of the product from said second reaction chamber.

27. A method as in claim 26, wherein said stream of said product flows counter-currently with said second portion of said mixed-feed.

28. A method as in claim 25, comprising the further step of providing communication means between said first reaction chamber and said second reaction chamber, whereby a stream of the product flows from or to said first reaction chamber to or from said second reaction chamber.

29. A method as in claim 25, comprising the further step of withdrawing a stream of the product from said first reaction chamber.

30. A method as in claim 29, wherein said stream of said product flows counter-currently with said first portion of said mixed-feed.

31. A method as in claim 25, wherein said first portion of said mixed-feed flows co-currently with a flow of flue gas in said combustion chamber.

32. A method as in claim 25, wherein said second portion of said mixed-feed flows counter-currently with said flue gas flowing from said first location to said second location in said convection chamber.

Third Draft 09/11/00

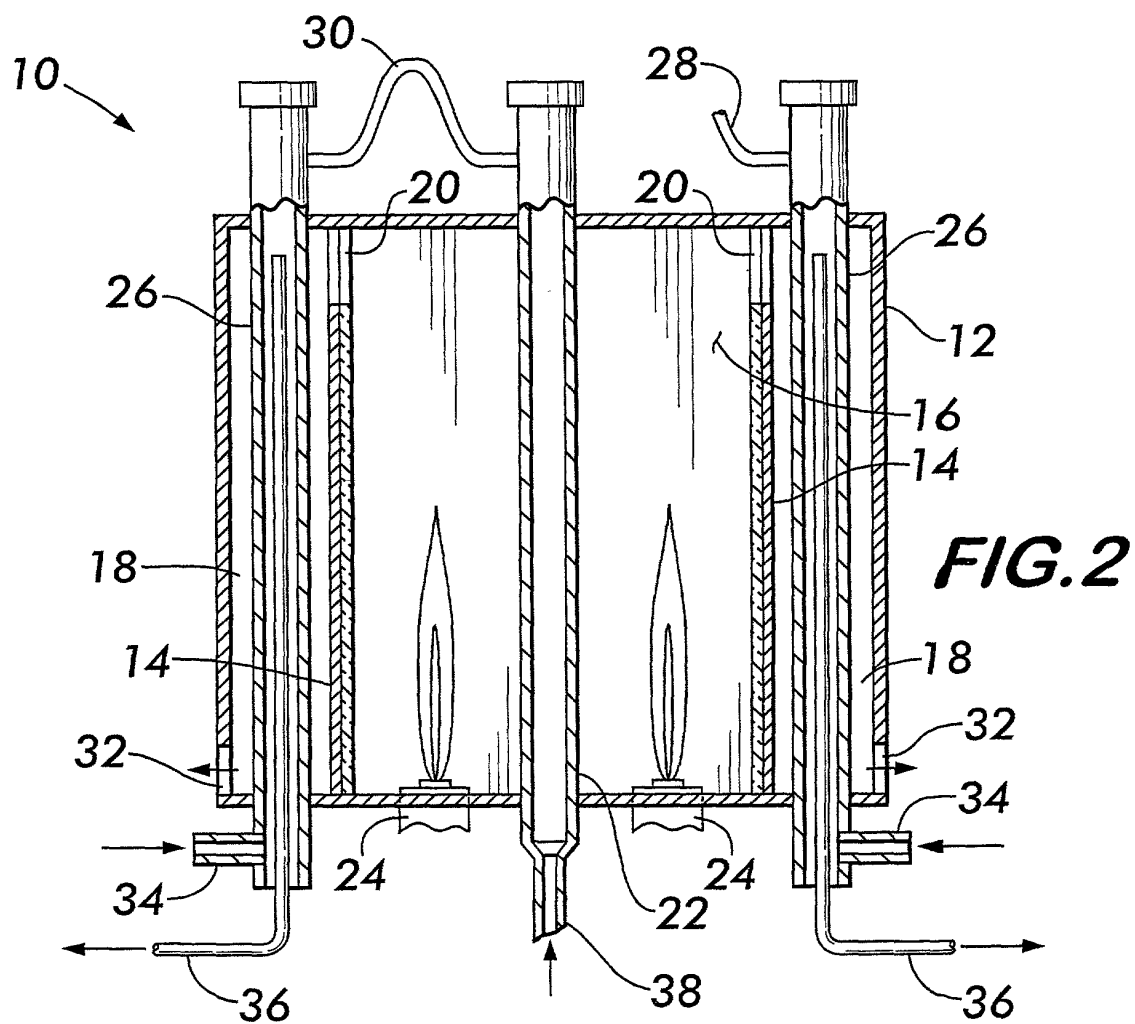
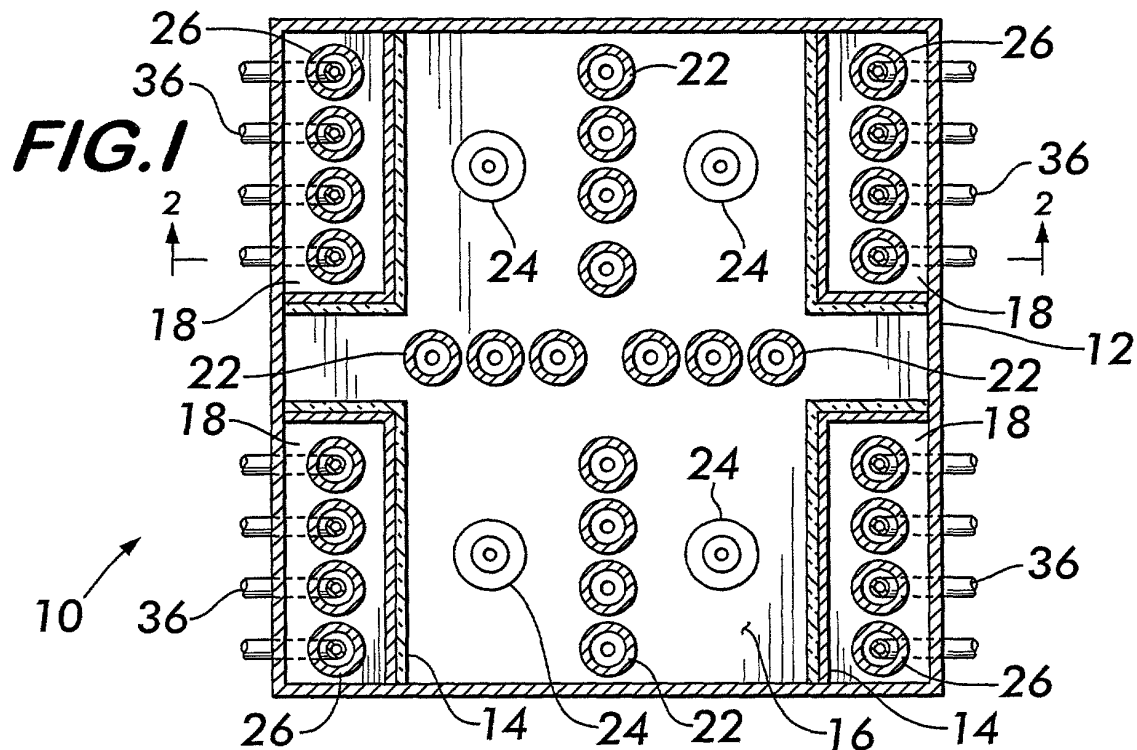
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## ABSTRACT OF THE DISCLOSURE

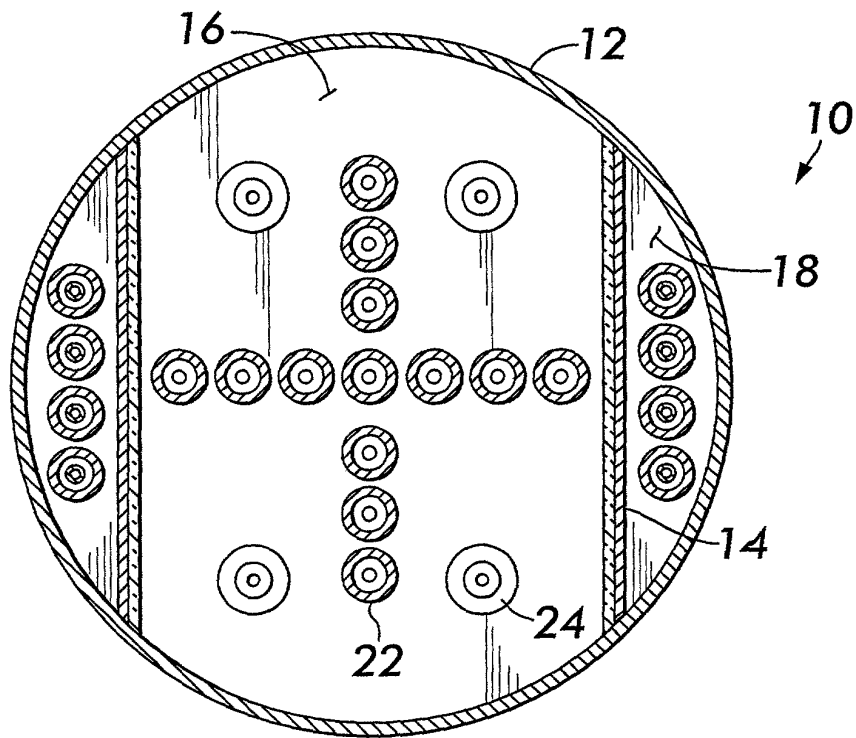
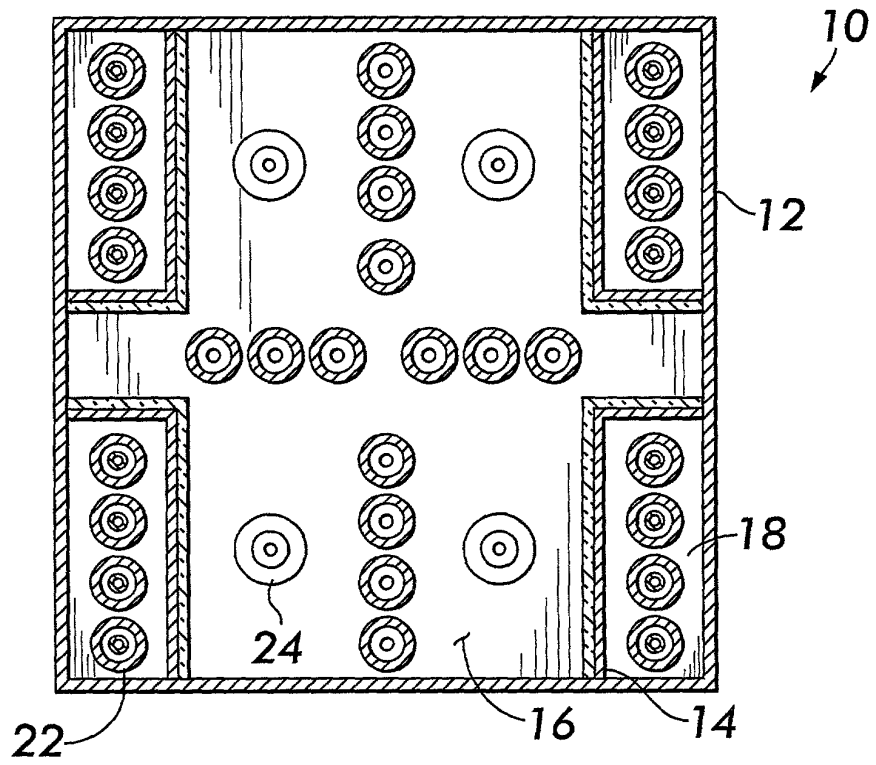
5           The present invention is an apparatus arranged to maximize heat utilization for a hydrocarbon steam reforming process to produce synthesis gas. The apparatus comprises a refractory lined vessel with partition walls that divide the inside of the vessel into (1) a combustion chamber(s) containing one or more burners, and (2) convection chambers used as a means to remove combustion products from the combustion chamber through one or more openings at the opposite end of the burner end. The combustion chamber contains one or more reformer tubes in which a mixed-feed of hydrocarbon and steam flow co-current with combustion products and receive direct radiant heat from the combustion flame through the tube wall. The convection chambers contain a tube-in-tube device filled with catalyst in the annuli. The mixed-feed in the annuli flows counter-current with combustion products and the hot product synthesis gas, and thereby substantially lowers the temperature of the combustion and product gases before the gases exit the furnace. High emissivity materials or walls are used inside the convection chambers to enhance the heat transfer from the flue gas to the reformer tubes.

## SEQUENCE LISTING

Not applicable.

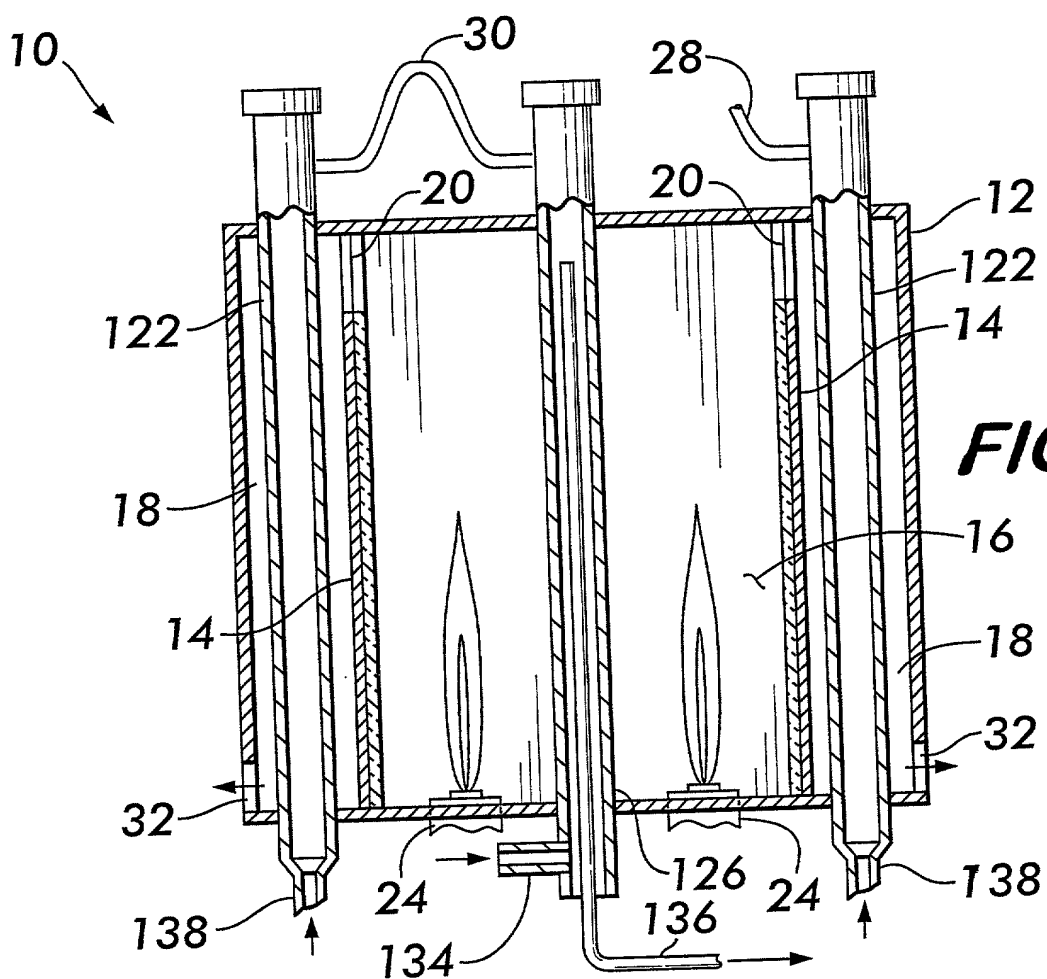
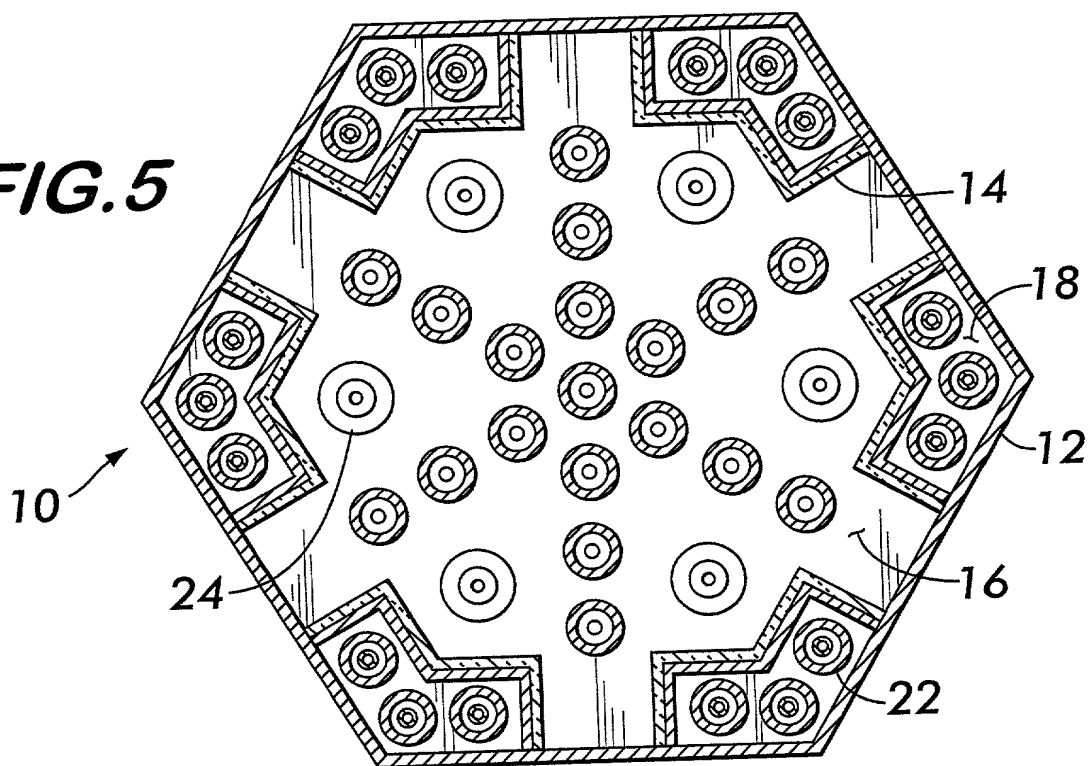


**FIG.3**



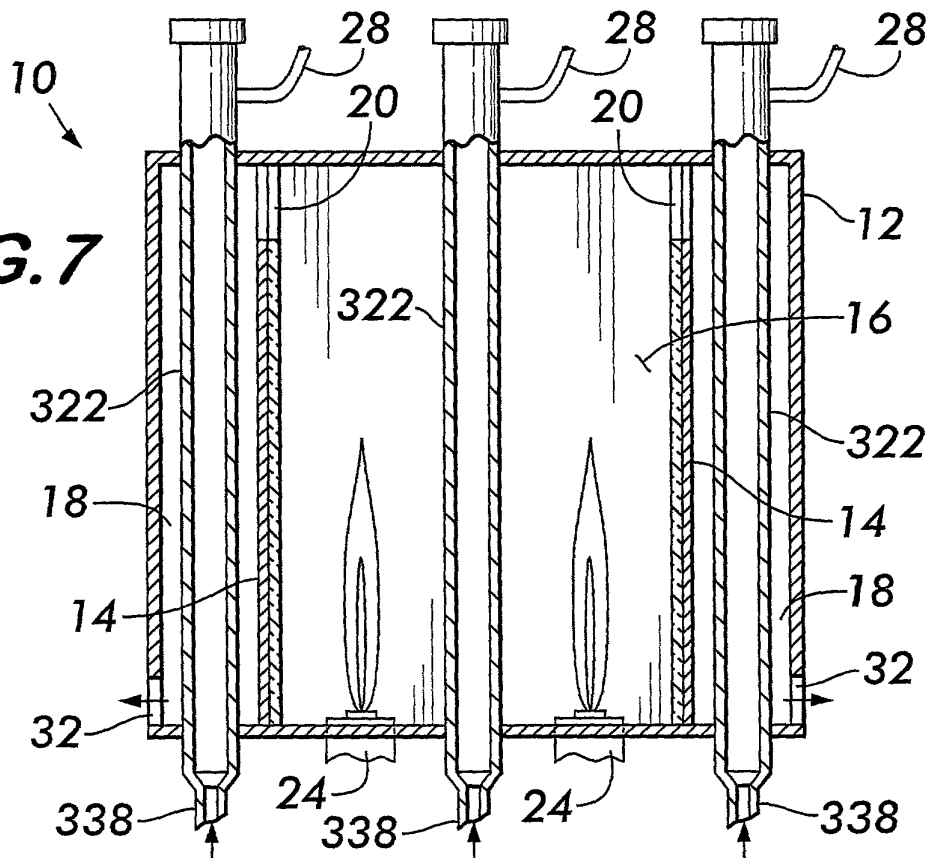
**FIG.4**

**FIG. 5**



**FIG. 6**

**FIG. 7**



**FIG. 8**

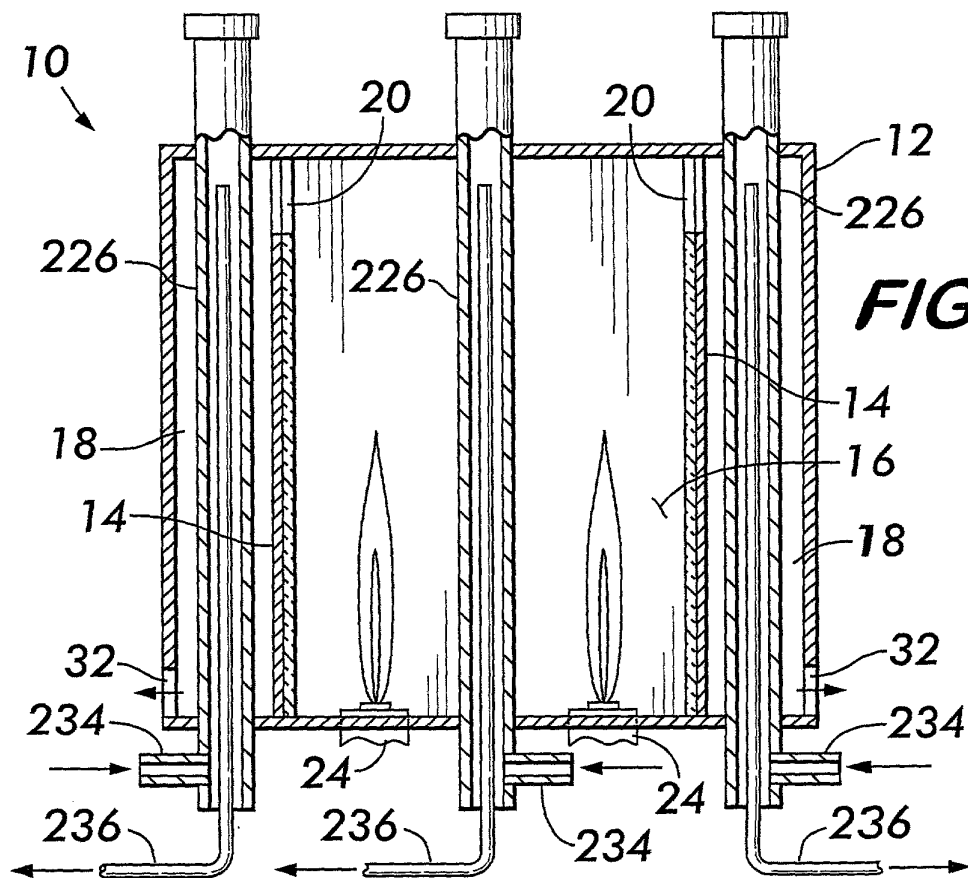




FIG. 9 is a top view of a rectangular board game, such as a backgammon board, showing the arrangement of points and pieces. The board is divided into two main sections, each containing a series of points (indicated by circles) and a central area (indicated by a shaded rectangle). The points are arranged in a symmetrical pattern, with a central point (indicated by a circle) and a series of points (indicated by circles) on either side. The central area is defined by a shaded rectangle, and the points are arranged in a series of rows and columns. The board is labeled with the number 10 in the bottom left corner.

10

FIG. 9

24

22

16

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14

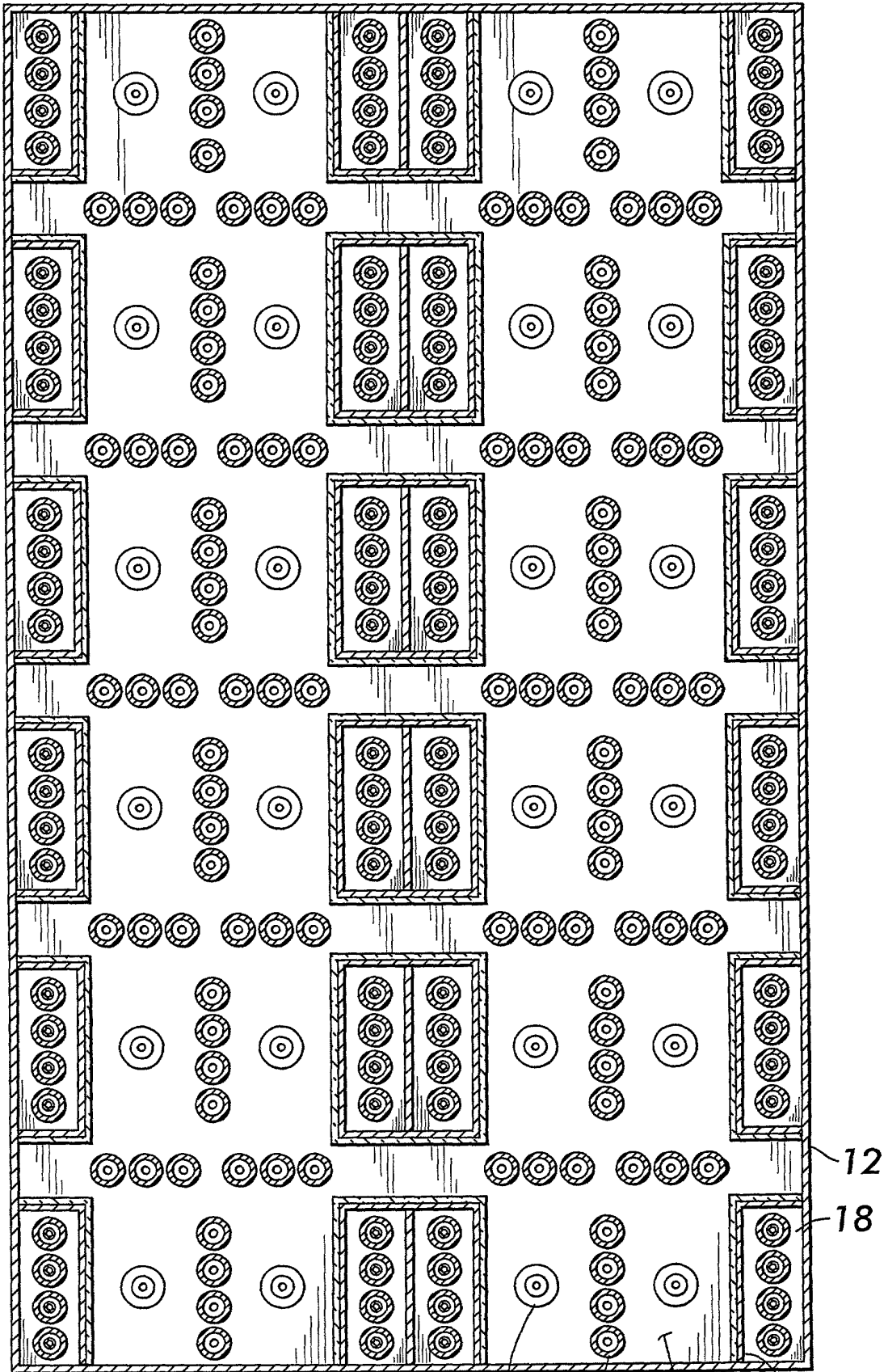
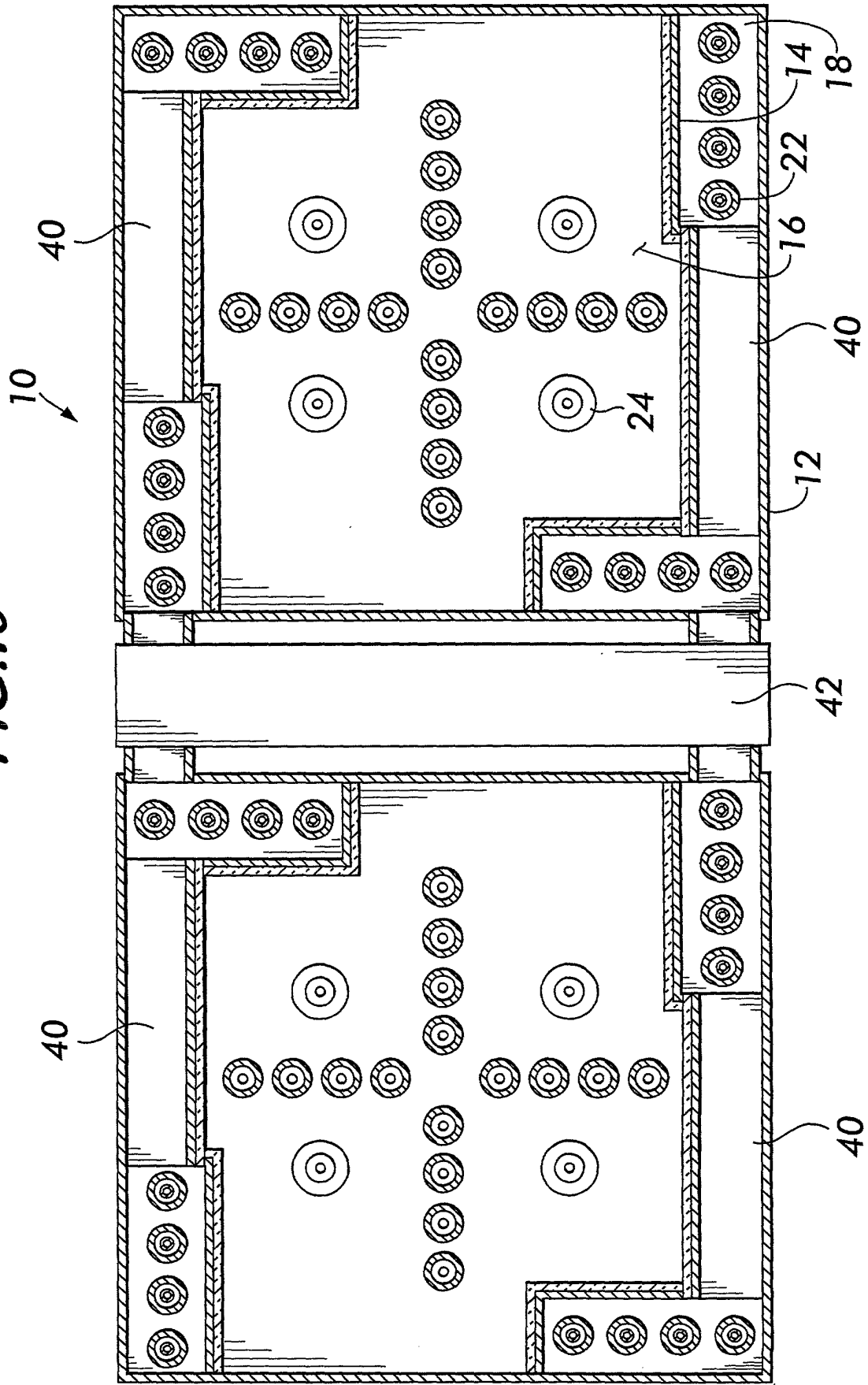
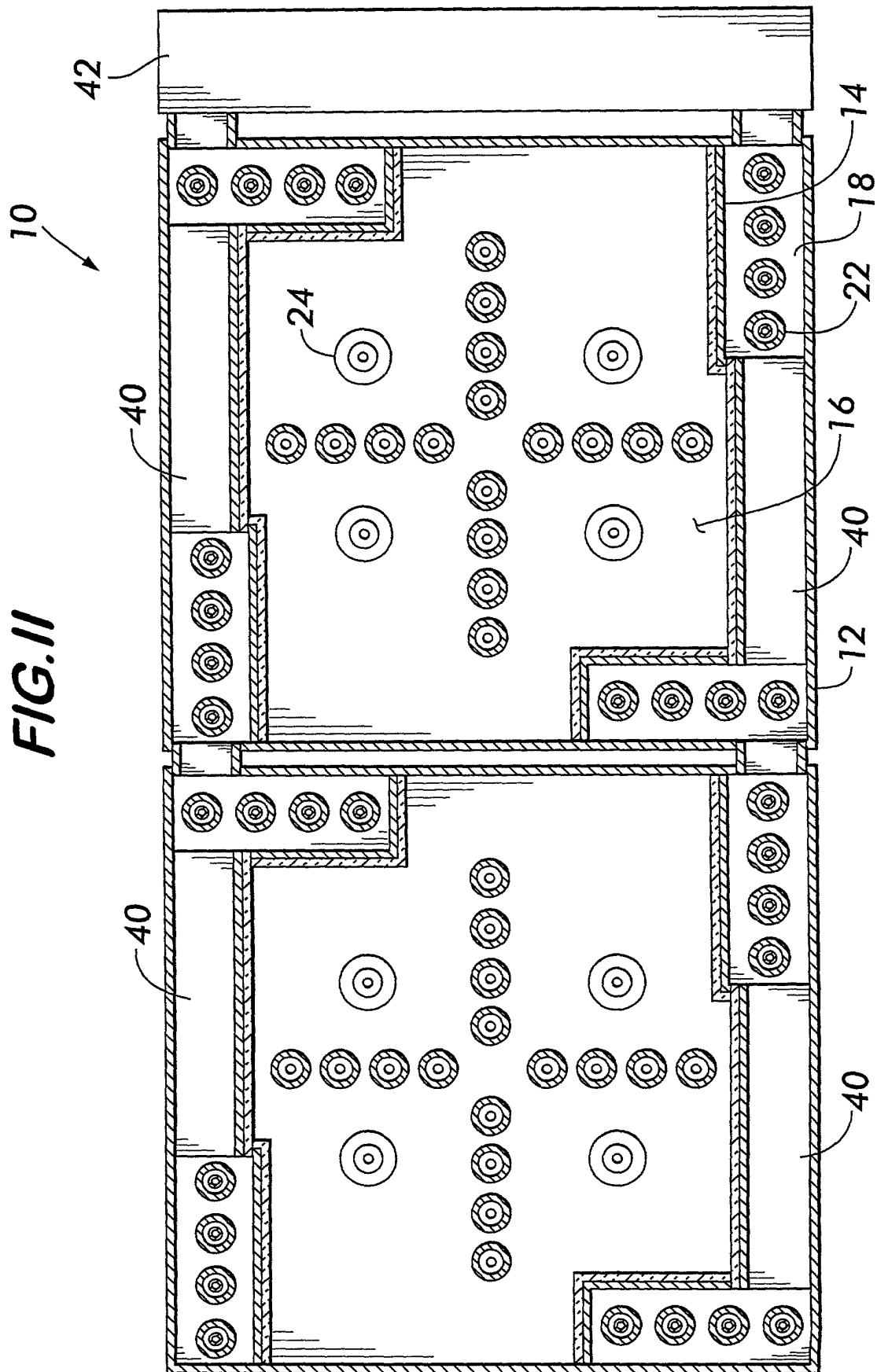


FIG. 10





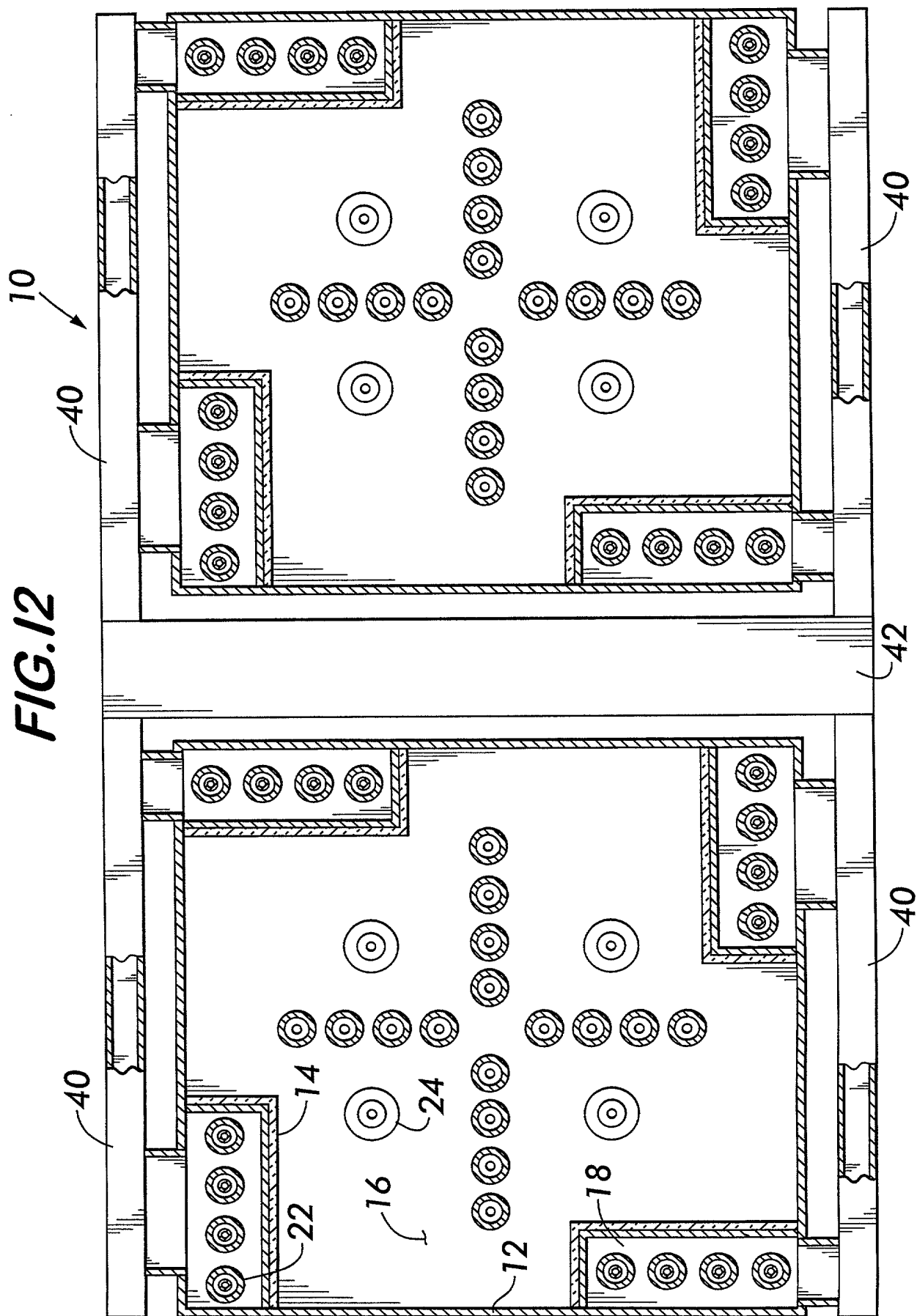


FIG. 13

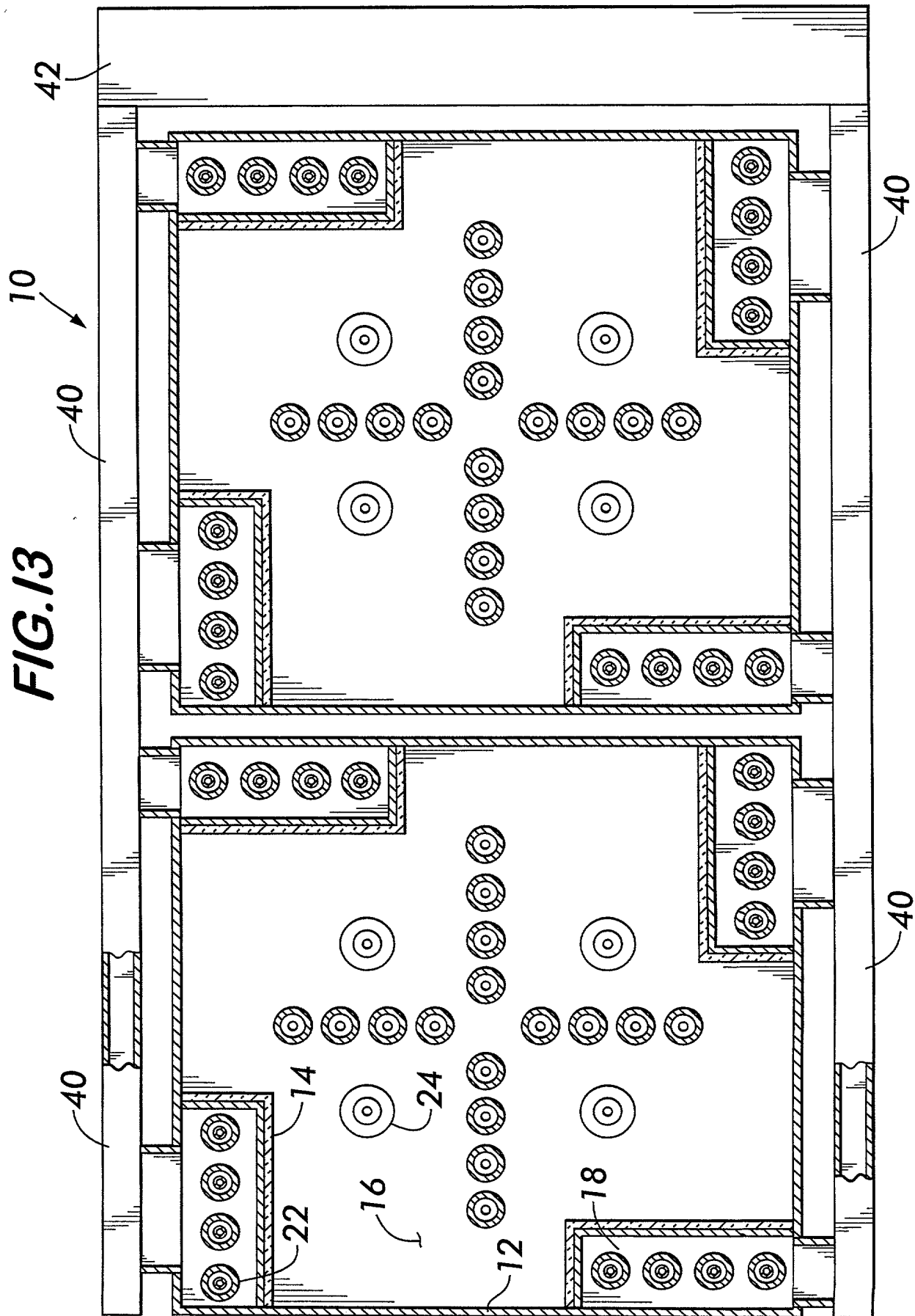


FIG.14

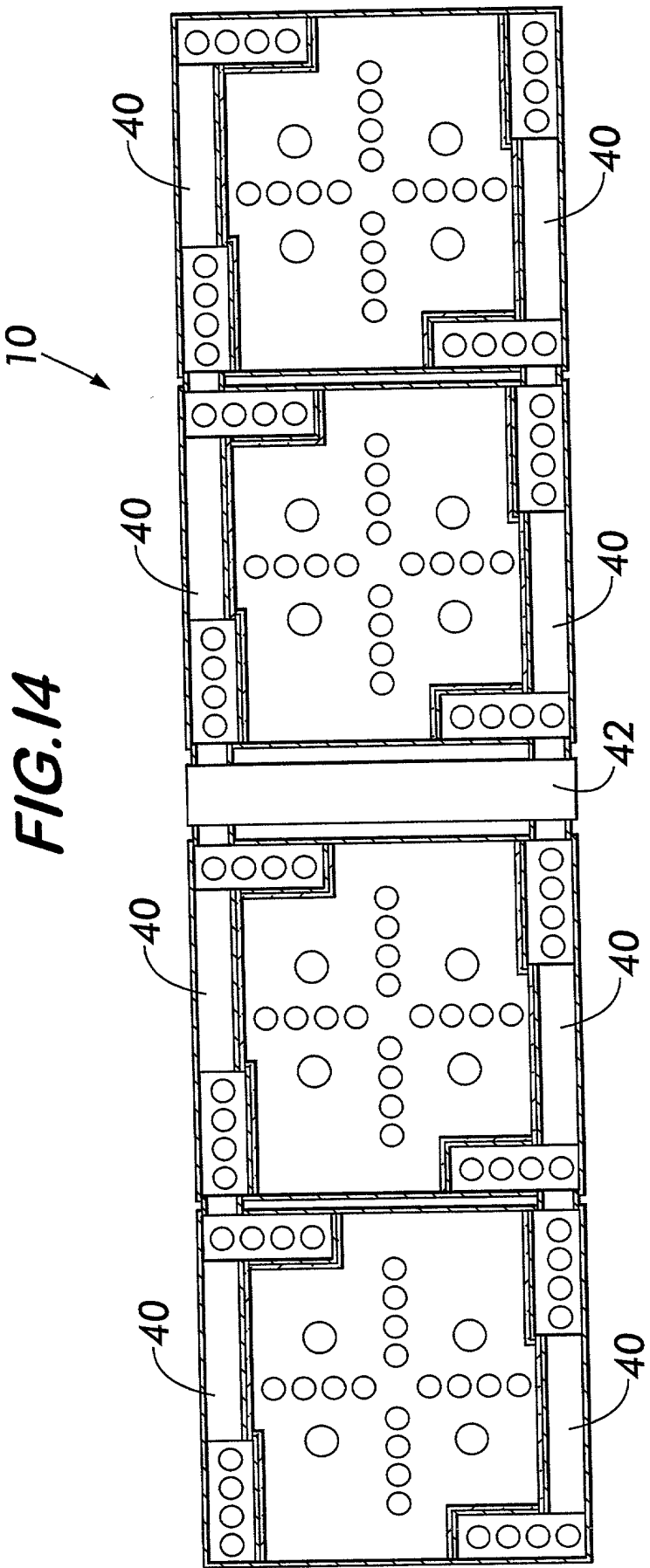
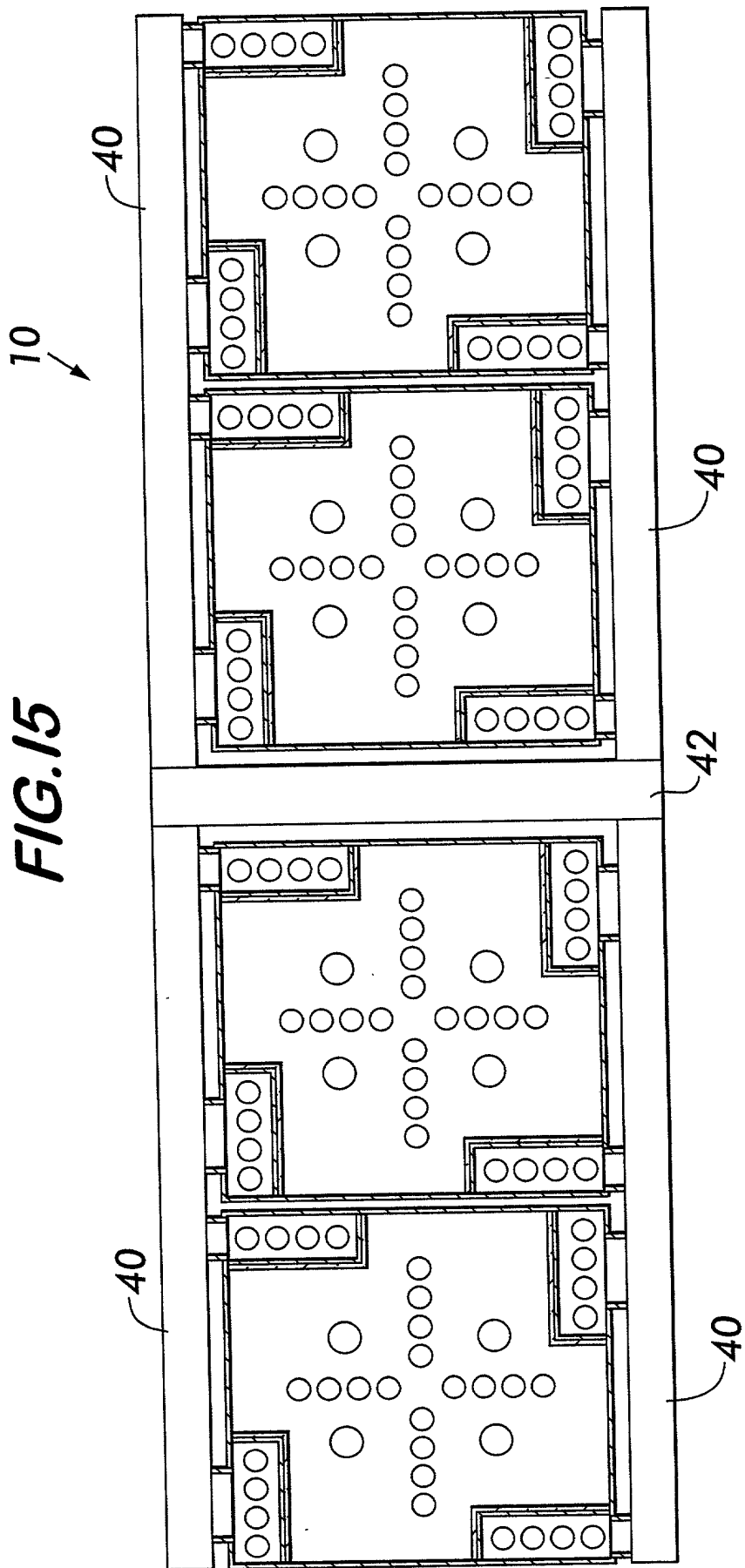
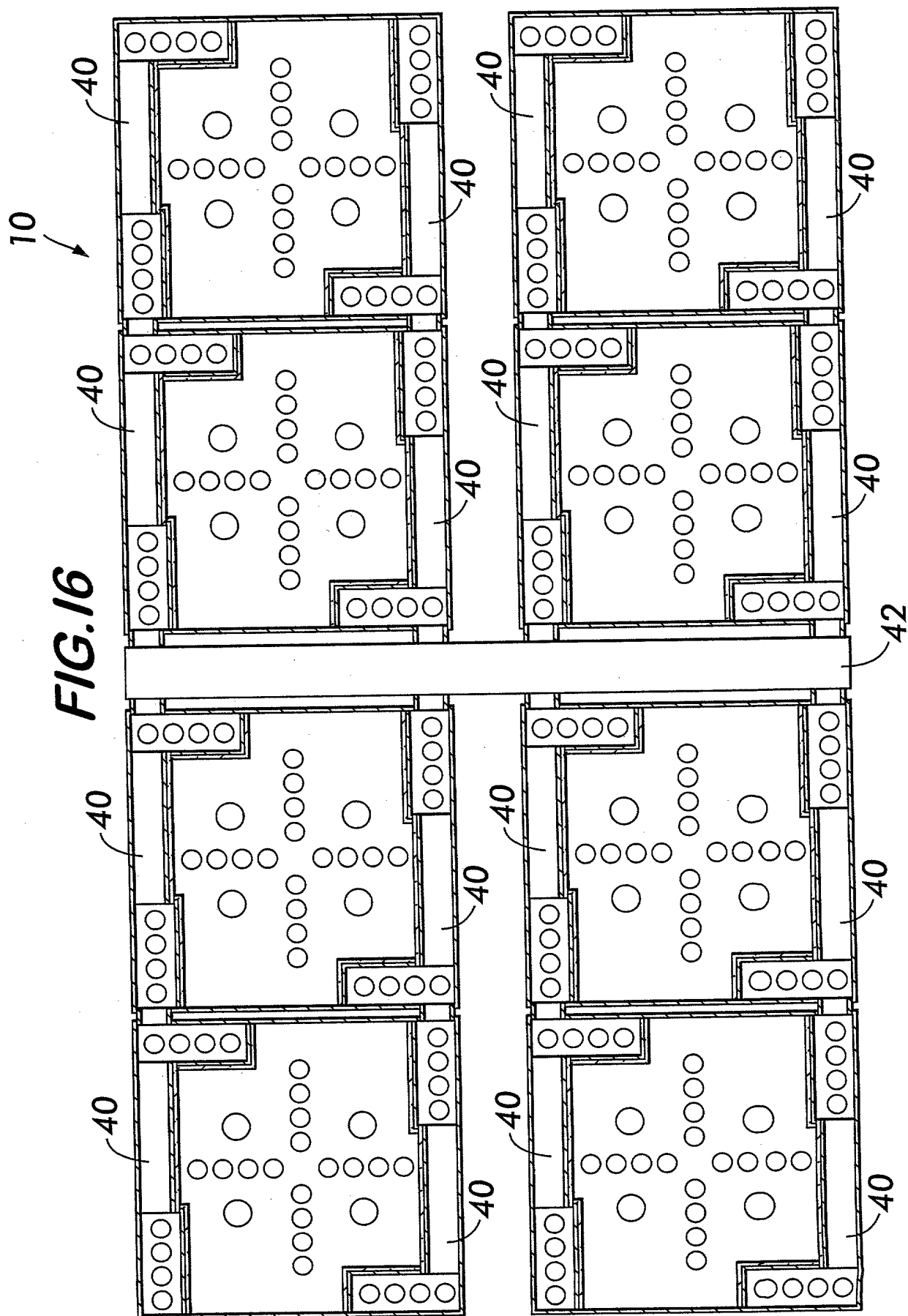
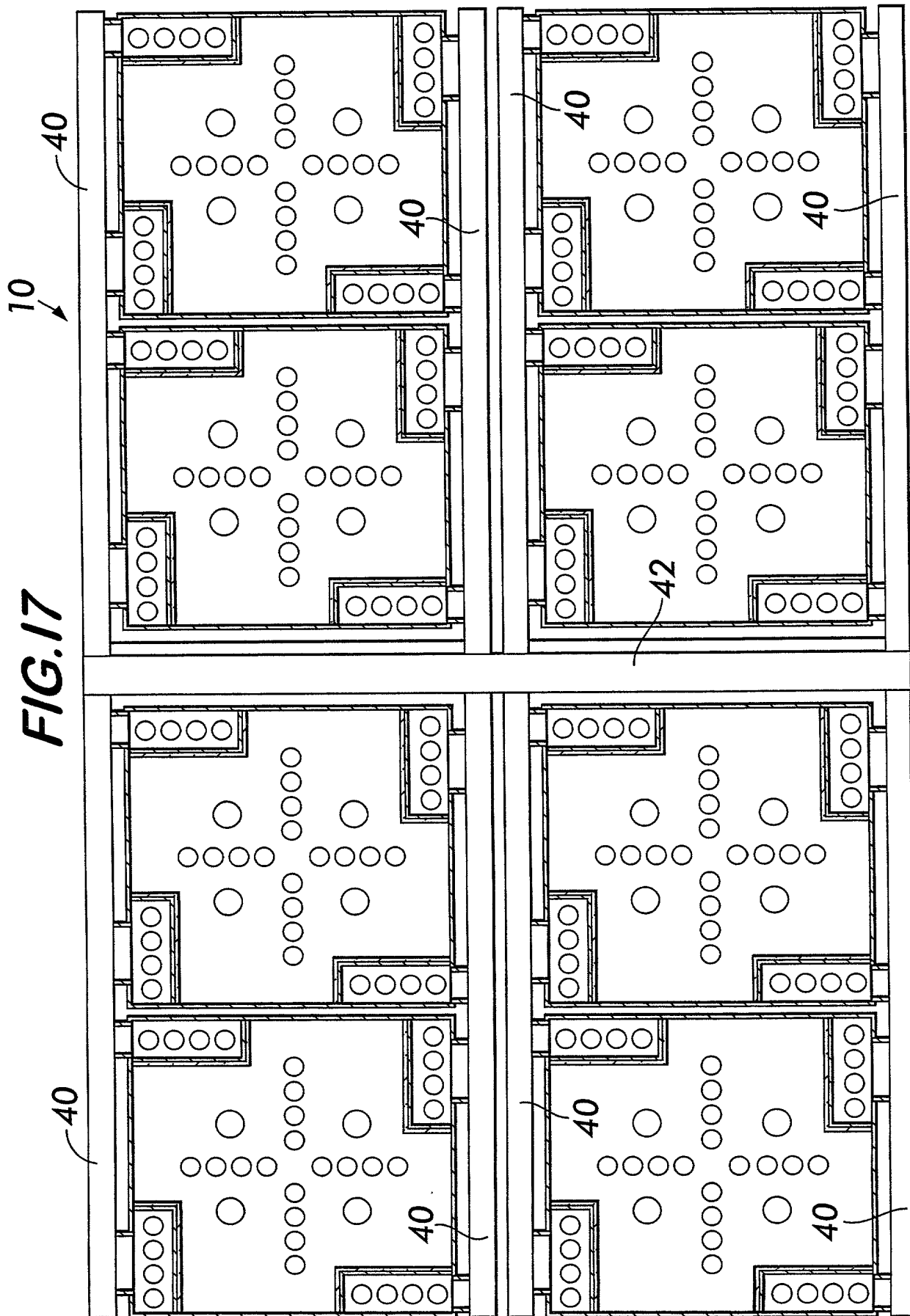


FIG. 15

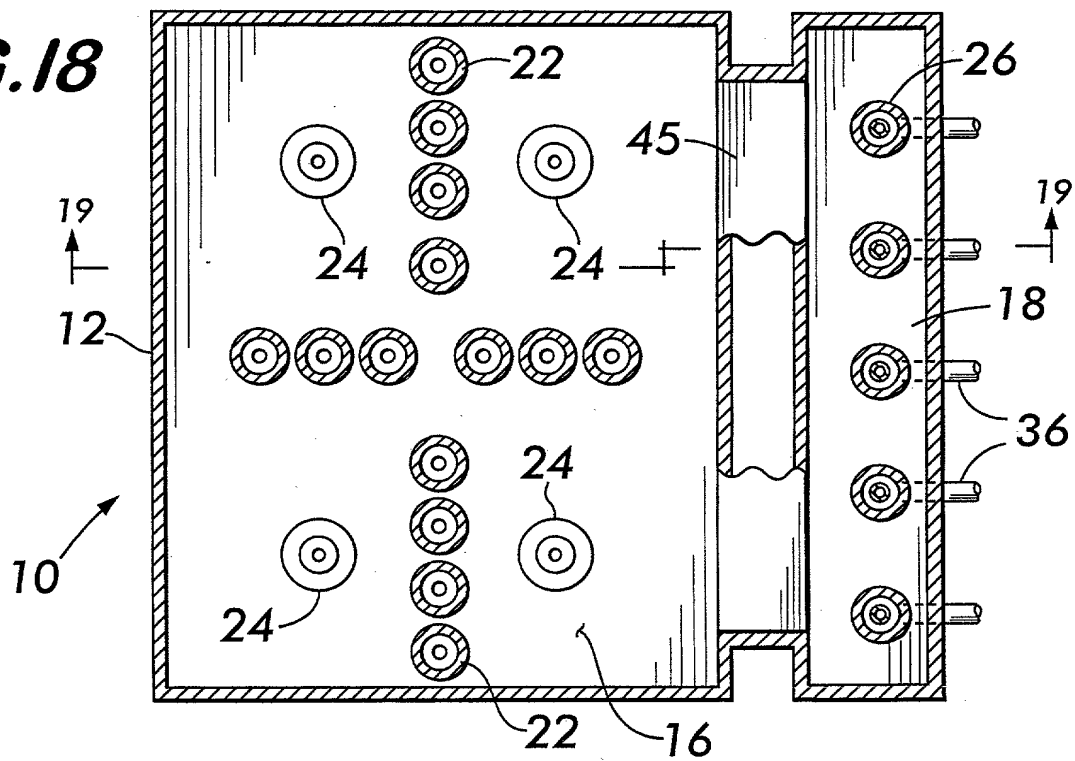




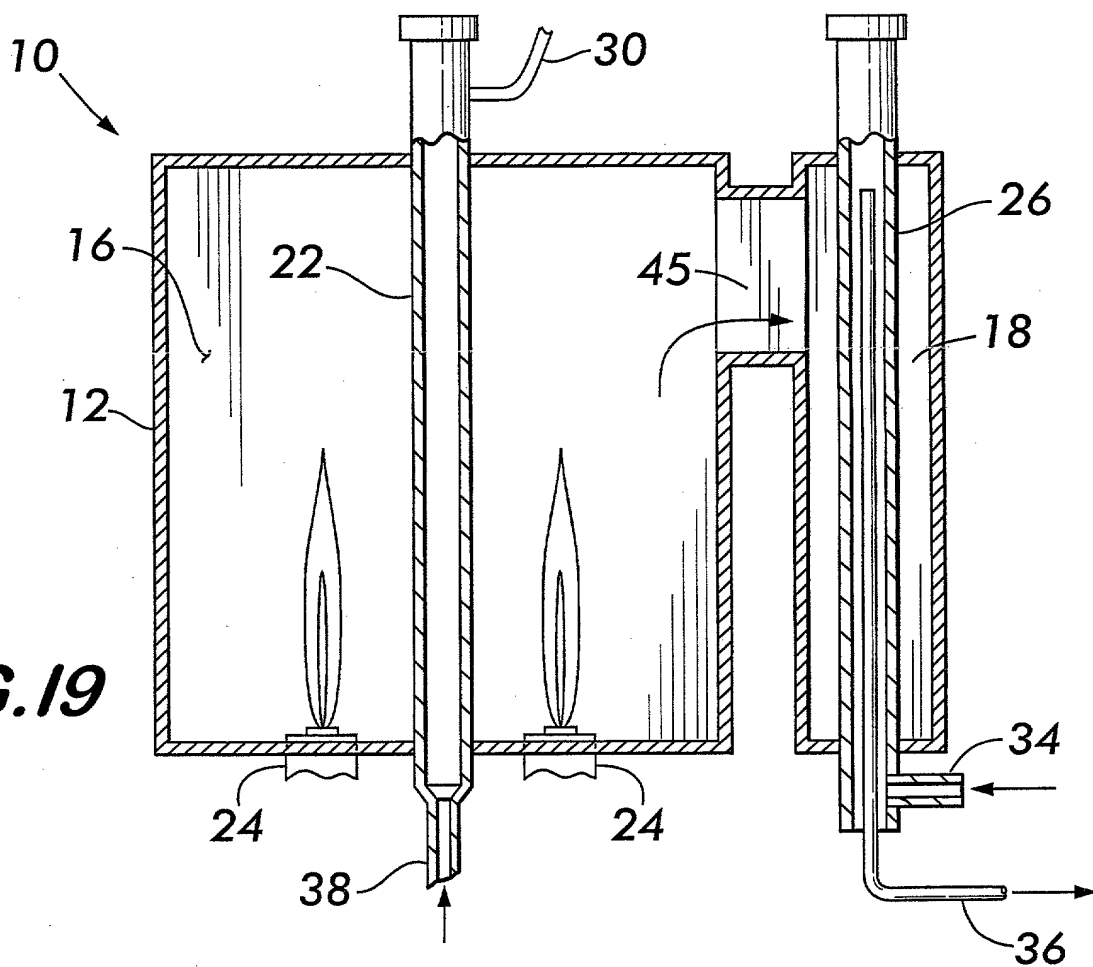





**FIG.18**



**FIG.19**



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**DECLARATION FOR UTILITY OR  
DESIGN  
PATENT APPLICATION  
(37 CFR 1.63)**

☒ Declaration Submitted with Initial Filing **OR** ☐ Declaration Submitted after Initial Filing (surcharge (37 CFR 1.16 (e)) required)

Attorney Docket Number 06052 USA

First Named Inventor Hoanh Nang Pham

**COMPLETE IF KNOWN**

Application Number /

Filing Date September 20, 2000

Group Art Unit

Examiner Name

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

Apparatus And Method For Hydrocarbon Reforming Process

the specification of which (Title of the Invention)

☒ is attached hereto  
OR

☐ was filed on (MM/DD/YYYY) as United States Application Number or PCT International

Application Number and was amended on (MM/DD/YYYY) (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached?	
				YES	NO
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

☐ Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto:

I hereby claim the benefit under 35 U.S.C. 119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Date (MM/DD/YYYY)	<input type="checkbox"/> Additional provisional application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

[Page 1 of 2]

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## DECLARATION — Utility or Design Patent Application

I hereby claim the benefit under 35 U.S.C. 120 of any United States application(s), or 365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. Parent Application or PCT Parent Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number (if applicable)

☐ Additional U.S. or PCT international application numbers are listed on a supplemental priority data sheet PTO

As a named inventor, I hereby appoint the following registered practitioner(s) to prosecute this application and to maintain communication with the Patent and Trademark Office connected therewith:

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☐ Registered practitioner(s) name/registration number listed below



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Air Products and Chemicals, Inc.

Name	Registration Number	Name

☐ Additional registered practitioner(s) named on supplemental

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23543

Air Products and Chemicals, Inc.

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of Sole or First Inventor:

☐ A petition has been filed for this unsigned inventor

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		ZIP	18104
		Country	USA

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Inventor's Signature						9/19/00 Date	✓
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Post Office Address							
City	Macungie	State	PA	ZIP	18062	Country	USA
Name of Additional Joint Inventor, if any:		<input type="checkbox"/> A petition has been filed for this unsigned inventor					
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Name of Additional Joint Inventor, if any:		<input type="checkbox"/> A petition has been filed for this unsigned inventor					
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Scott David				Madara			
Inventor's Signature						9/24/2000 Date	✓
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Post Office Address							
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Given Name (first and middle [if any])				Family Name or Surname			
Joel Charles				MacMurray			
Inventor's Signature						Date	<u>19 Sept 00</u>
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Post Office Address							
City	Emmaus	State	PA	ZIP	18049	Country	USA
<b>Name of Additional Joint Inventor, if any:</b>		<input type="checkbox"/> A petition has been filed for this unsigned inventor					
Given Name (first and middle [if any])				Family Name or Surname			
Inventor's Signature						Date	
Residence: City		State		Country		Citizenship	
Post Office Address							
Post Office Address							
City		State		ZIP		Country	
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Inventor's Signature						Date	
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